

# Waste Management

## Nutrient Movement and Removal in a Switchgrass Biomass-Filter Strip System Treated with Dairy Manure

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### ABSTRACT

Manure use on cropland has raised concern about nutrient contamination of surface and ground waters. Warm-season perennial grasses may be useful in filter strips to trap manure nutrients and as biomass feedstock for nutrient removal. We explored the use of 'Alamo' switchgrass (*Panicum virgatum* L.) in a biomass production-filter strip system treated with dairy manure. We measured changes in extractable P in the soil,  $\text{NO}_3\text{-N}$  in soil water, and changes in total reactive P and chemical oxygen demand (COD) of runoff water before and after a switchgrass filter strip. Five rates of dairy manure (target rates of 0, 50, 100, 150, and 200 kg N ha<sup>-1</sup> from solid manure in 1995; 0, 75, 150, 300, and 600 kg N ha<sup>-1</sup> from lagoon effluent in 1996 and 1997) were surface-applied to field plots of switchgrass (5.2 by 16.4 m) with a 5.2- by 16.4-m switchgrass filter strip below the manured area. Yield of switchgrass from the manured area increased linearly with increasing manure rate in each year. Soil water samples collected at 46 or 91 cm below the soil surface on 30 dates indicated <3 mg L<sup>-1</sup> of  $\text{NO}_3\text{-N}$  in all plots. Concentrations of total reactive P in surface runoff water were reduced an average of 47% for the 150 kg N rate and 76% for the 600 kg N rate in 1996 and 1997 after passing through the strip. Manure could effectively substitute for inorganic fertilizer in switchgrass biomass production with dual use of the switchgrass as a vegetative filter strip.

LARGE confined animal feeding operations have become common in the dairy industry in central Texas and other regions. A sustainable dairy industry depends in part on its ability to manage animal manure, prevent or reduce potential adverse environmental effects, and utilize manure as a resource. Contamination of ground water by  $\text{NO}_3\text{-N}$  has been a concern, but high levels of P from land application of animal manure can become a major problem in surface soils and runoff water (Sharpley and Withers, 1994).

The water quality of the Upper North Bosque river in Erath County, Texas has been degraded by point- and nonpoint-source pollution (Texas Water Commission and Texas State Soil and Water Conservation Board, 1991). High nutrient concentrations in the North

Bosque River have been attributed in part to the density of dairy cows (*Bos taurus*) and the proportion of land area used for manure application on certain microwatersheds (McFarland and Hauck, 1999). Typically, dairies in this area collect manure and runoff from holding areas in lagoons and retention ponds, stockpile and land-apply solid manure from drylots, and separate fibrous solids from liquid slurry via mechanical screens (Sweeten and Wolfe, 1994). Most of the liquid and solid manure is applied to forage crops such as 'Coastal' bermudagrass [*Cynodon dactylon* L. (Pers.)].

The farm and nonfarm public interspersed among these animal operations are concerned about the use of the manure on cropland and its subsequent effect on ground and surface waters. Downstream city dwellers, whose water supply is Lake Waco in the lower portion of the North Bosque watershed, are also concerned about water quality. Alternative outlets for use of manure nutrients must be developed to reduce the waste stream and loss of nutrients from the system.

Switchgrass has been identified as a versatile grass for use in soil and water conservation, forage production, and as a biomass feedstock for renewal energy production (Vogel, 1996; Sanderson et al., 1996, 1999; McLaughlin and Walsh, 1998). Warm-season grasses have proven effective as windbreaks for controlling wind erosion (Sajjadi and Zartman, 1990), as vegetative barriers for trapping sediment and reducing water erosion (Dabney et al., 1995), as filter strips for slowing surface runoff and reducing herbicide movement (Mersie et al., 1999), and as buffer strips for protecting riparian zones (Schnabel, 2000). We propose a novel multi-purpose cropping system in which switchgrass serves both as a receiver crop for dairy manure and as a vegetative filter strip. Nutrients would be removed in biomass harvested from the manured area and the biomass used as feedstock for conversion to energy or as livestock forage. An untreated area of switchgrass below the manured field could act as a vegetative filter strip to reduce concentrations of nutrients in surface runoff water.

The objectives of this 3-yr field-plot experiment were to (i) determine switchgrass dry matter (DM) yield response to dairy manure, (ii) determine accumulation of P in the soil and  $\text{NO}_3\text{-N}$  levels in soil water under manured switchgrass, and (iii) measure changes in water quality constituents of surface runoff water from

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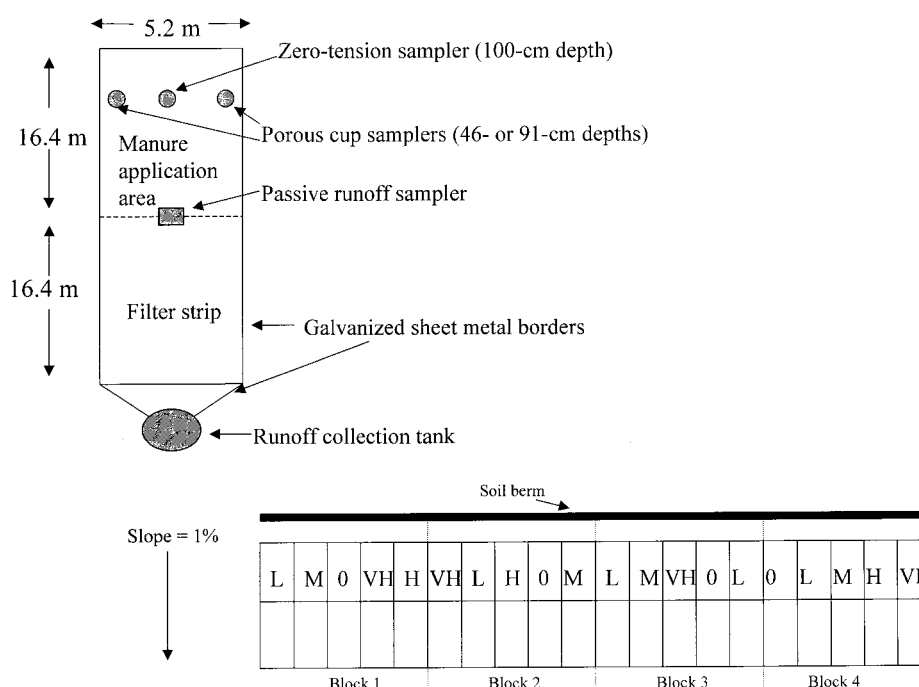


Fig. 1. Schematic of field plot design and arrangement. Not to scale. O, no manure; L, low manure rate; M, medium rate; H, high rate; VH, very high rate of manure. Surface runoff was sampled only from plots O, M, and VH in each block. Soil water samplers were installed in each plot.

switchgrass stands treated with dairy manure before and after filter strip treatment.

## MATERIALS AND METHODS

A field plot study was conducted on a 2-yr-old stand of 'Alamo' switchgrass at the Texas A&M University Agricultural Research and Extension Center at Stephenville, TX. Soil at the site is a Windthorst fine sandy loam (fine, mixed, thermic Udic Paleustalf; Soil Survey Staff, 1970). Soil pH was 5.8 with  $\text{NO}_3\text{-N}$  of  $1 \text{ mg kg}^{-1}$ , available P of  $8.5 \text{ mg kg}^{-1}$ , and available K of  $117 \text{ mg kg}^{-1}$  in the top 15 cm. Soil in the upper 18 cm was 71% sand, 10% silt, and 19% clay, with an organic matter content of  $7.5 \text{ g kg}^{-1}$ . Soil texture changes to 50% sand, 12% silt, and 33% clay extending to 96 cm. Infiltration rate was  $1.5$  to  $5 \text{ cm h}^{-1}$  in the surface 64 cm (Soil Survey Staff, 1976). Field plots were 5.2 m wide and 32.8 m long (slope = 1%) and were separated by a galvanized sheet metal barrier inserted 30 cm deep in the soil (Fig. 1). The barrier extended 18 cm above the soil. The upper half (5.2 by 16.4 m) of the plot was used for manure and lagoon effluent application and the downslope half was used as a vegetative filter strip (manured area to filter strip area ratio of 1.0). A small soil berm was constructed across the top of the plots to divert surface runoff water from fields above the plots.

In the first year of the study (1995), we used solid dairy

manure scraped from a dairy drylot. Five manure treatments were spread by hand and provided target rates of approximately 0, 50 (low rate), 100 (medium rate), 150 (high rate), and 200 (very high rate)  $\text{kg N ha}^{-1}$  and were arranged in a randomized complete-block design with four replications (20 plots). In response to producer concerns about the use of dairy lagoon effluent on cropland, we switched to using lagoon effluent and higher N rates in 1996 and 1997. Lagoon effluent was applied at target rates of 0, 75 (low), 150 (medium), 300 (high), and 600 (very high)  $\text{kg N ha}^{-1}$ . The same plots received the same target rates each year. The effluent was pumped on to the soil surface with a system of gated pipes and hoses along the length of the upper half of the plot. Fresh water was used to equalize water application rates across the treatments in 1996 and 1997 to prevent confounding treatment effects.

Manure was applied once in 1995. In 1996 and 1997, the total annual manure amount was divided among four to six applications during spring and summer. At each application, four 1-kg samples of manure or 1-L samples of effluent were collected for nutrient analyses. Composition and rates of manure, lagoon effluent, and fresh water applied in each year are in Tables 1 and 2. The rates were based on manure as it was sampled at the time of application and were not adjusted for N volatilization loss or N availability. Deviation from target N application rates resulted from estimating manure N concen-

Table 1. Composition of solid dairy manure (1995) or lagoon effluent (1996, 1997) at each application date. Data are means of four replicate samples per date.

Date	Total N	Total P	K	Date	Total N	Total P	K	Date	Total N	Total P	K
mg kg <sup>-1</sup> wet wt.			mg L <sup>-1</sup>				mg L <sup>-1</sup>				
19 May 1995	8500	4300	7700	16 Apr. 1996	309	63	587	6 May 1997	270	60	560
				1 May 1996	325	52	614	29 May 1997	290	50	530
				20 May 1996	298	46	549	20 June 1997	280	40	530
				25 June 1996	238	52	655	9 July 1997	300	50	530
								21 July 1997	310	50	820
								6 Aug. 1997	320	40	870

**Table 2. Total amounts of manure, N, and P applied during 1995 to 1997. Target N rates are in parentheses. Total amounts for N and P include that applied in the fresh water.**

	1995	1996		1997	
	Manure	Effluent	Fresh water†	Effluent	Fresh water†
	Mg ha <sup>-1</sup>	L m <sup>-2</sup>			
Low	5	25	115	15	199
Medium	10	49	110	31	184
High	15	98	72	61	153
Very high	20	195	8	122	92
	kg N ha <sup>-1</sup>				
Low	43 (50)	73 (75)		83 (75)	
Medium	83 (100)	145 (150)		162 (150)	
High	125 (150)	291 (300)		322 (300)	
Very high	168 (200)	580 (600)		642 (600)	
	kg P ha <sup>-1</sup>				
Low	21	19		23	
Medium	43	32		34	
High	64	56		59	
Very high	85	106		108	

† Fresh water contained 4.85 mg L<sup>-1</sup> total P and 1.2 mg L<sup>-1</sup> total N.

tration before obtaining the laboratory analysis. Testing manure before land application is a recommended best management practice. We chose to apply manure before testing because of previous research experience with solid manure (Sanderson and Jones, 1997) and lagoon effluent (Sweeten and Wolfe, 1994) at Stephenville. Actual application rates of N were about 15% less than the target rate in 1995, about 3% less in 1996, and 6% greater than the target rate in 1997 (Table 2).

Switchgrass was harvested in September or October each year. A sickle-bar plot harvester was used to cut a 1.5- by 6-m strip at a 15-cm stubble height from the center of the manured-treated half of each plot. The remaining switchgrass was then cut and removed from the entire plot. Biomass yield was not measured in the filter strip because we assumed that yields from the plots that did not receive manure would be similar to biomass yields from the untreated filter strips. Samples for DM determination and chemical analysis (total N and P) were dried at 55°C for 48 h.

Soil samples were collected before the start of the experiment in March 1995 (15-cm increments to a depth of 120 cm) to characterize initial levels of extractable P. Ten cores were collected across each of the four blocks and composited by depth within each block. Cores were collected from the 0- to 15- and 15- to 30-cm depths in the treated and filter strip portions of the plots in April 1996 and in April and November of 1997 (end of the experiment) to monitor changes in soil P. At each soil sampling, four cores were collected in each plot area and composited by depth.

Suction samplers (Angle et al., 1991) constructed of 3.8-cm-diam. PVC pipe and porous ceramic cups (1 bar high-flow cups, Soil Moisture Equipment, Santa Barbara, CA) were installed in March 1995 at 46 and 91 cm below the soil surface as described by Sanderson and Jones (1997). Zero-tension soil water samplers (Simmons and Baker, 1993) were installed to a 100-cm depth at a 30° angle. One suction sampler was installed at each depth and one zero-tension sampler was installed in the manured portions of each plot. Soil water was sampled for nitrate N after each rainfall; however, water was not obtained from every sampler at every event.

A surface runoff water sampler (30 by 30 cm; based on the design of Daniels and Gilliam, 1996) was installed flush with the soil surface at the midpoint of the zero, medium, and very high rate manure rate plots to sample runoff water from the

manure-treated area (Fig. 1). All runoff water was diverted into a gravity-fed 416-L collection tank in a pit downslope from the switchgrass filter strip. The tanks overflowed during some large rains and runoff events. The overflow was diverted away from the tank and plot. Subsamples (1 L) of runoff water were taken from the collection tank for comparison with the samples from the midpoint of the plot to determine the effectiveness of switchgrass as a filter strip. Runoff water samples were taken on an event basis and stored at 4°C until analysis.

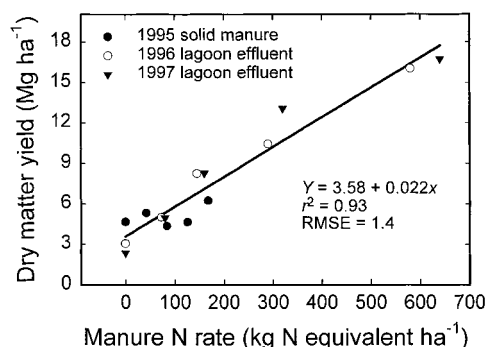
Total N concentration of switchgrass samples was determined by a modified Kjeldahl method (block digester) and colorimetric measurement with an autoanalyzer (Association of Official Analytical Chemists, 1991). The same digest was used to determine total P with the molybdate-reactive method (Murphy and Riley, 1962). Manure and soil samples were analyzed by the Texas A&M University Soil Testing Laboratory (Texas Agricultural Extension Service, 1980). Extractable P in soil was determined according to Hons et al. (1990). Nitrate N in soil water samples was determined by a cadmium reduction method and colorimetric detection with an autoanalyzer (USEPA, 1974). Unfiltered runoff samples were analyzed for total reactive P by the ascorbic acid method (Greenberg et al., 1992). Runoff water from three dates in 1997 was also analyzed for COD (Jirka and Carter, 1975). Total N and P in fresh water was also measured (Association of Official Analytical Chemists, 1991).

The experiment was analyzed as a randomized complete block design in four blocks. Treatment sums of squares for significant ( $P < 0.05$ ) manure rate effects were decomposed into linear or quadratic single degree of freedom contrasts.

## RESULTS AND DISCUSSION

### Switchgrass Yield and Nutrient Uptake

Combined across years, switchgrass DM yields increased linearly with increased N applied from dairy manure (Fig. 2). In a study of switchgrass yield response to inorganic N adjacent to this experiment, we obtained DM yields of up to 19 Mg ha<sup>-1</sup> with 200 kg inorganic N (as ammonium nitrate) ha<sup>-1</sup> and a quadratic response function (Ocumpaugh et al., 1997). Differences in yield response to N in manure and N in inorganic fertilizer indicated that some of the N in the solid manure applied in 1995 had not mineralized or that large losses of N occurred, perhaps as ammonia volatilization from both the solid manure and lagoon effluent. Sweeten and Wolfe (1994) reported that ammonium N accounted for more than 90% of N in secondary lagoon effluent from



**Fig. 2. Dry matter (DM) yields during 1995 to 1997 as a function of manure N application rate. Data are means of four replicates. RMSE, root mean square error.**

**Table 3.** Apparent recovery of N and P in switchgrass biomass during 3 yr.

Rate	N recovered in forage	N applied in manure	N in forage from manure†	Apparent recovery‡	P recovered in forage	P applied in manure	P in forage from manure†	Apparent recovery‡
		kg ha <sup>-1</sup>		%		kg ha <sup>-1</sup>		%
None	35	0			12	0		
Low	56	200	21	10	19	62	7	11
Medium	90	391	55	14	30	109	18	16
High	144	738	109	15	39	180	27	15
Very high	189	1390	154	11	42	300	30	10

† Calculated as (nutrient recovered in forage from manure treatment) – (nutrient recovered in forage from control treatment).

‡ Calculated as  $100 \times [(\text{nutrient recovered in forage from manure treatment}) - (\text{nutrient recovered in forage from control treatment})] / \text{total nutrient applied}$ .

dairies near Stephenville. Volatilization may have been reduced, however, because the effluent was applied by overland flow under a closed canopy.

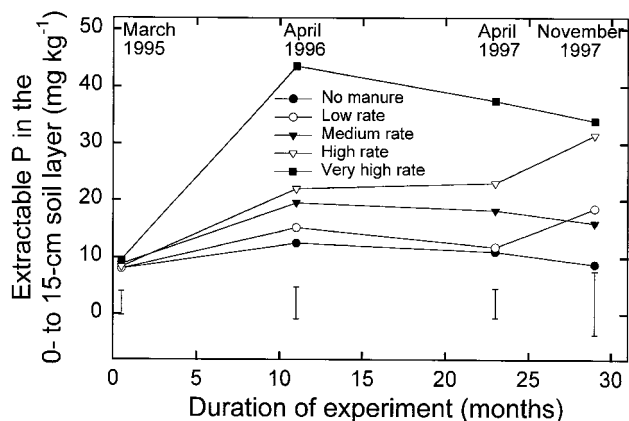
Apparent recovery of N and P in switchgrass biomass was low. Only about 10 to 15% of manure N and <20% of manure P was recovered in harvested biomass during the 3 yr of the study (Table 3). Nitrogen recovery may have been low because of slow mineralization of N in the solid manure applied in 1995 (Franzluebbers et al., 1995). In a study conducted near the same site, we measured apparent recoveries of 25 and 20% for N and P, respectively, from solid dairy manure applied to a bermudagrass–small grain forage system (Sanderson and Jones, 1997). Other studies have shown relatively low recovery of manure nutrients in forages. Apparent N recovery from liquid and solid dairy manure applied at 150 kg N ha<sup>-1</sup> to orchardgrass (*Dactylis glomerata* L.) during 2 yr was 40% for liquid manure and 26% for solid manure (Kanneganti and Klausner, 1994). Apparent N recovery from dairy slurry applied to a bermudagrass–ryegrass (*Lolium multiflorum* Lam.) sod in eastern Texas was less than 25% (Johnson et al., 1995).

### Soil Phosphorus

Use of manure may increase nutrient concentrations in the soil surface if manure nutrient application rates exceed crop uptake rates (Sharpley and Withers, 1994). Phosphorus accumulation in the surface soil layer is of concern because of the potential for transport of dissolved and particulate-bound P in surface runoff wa-

ter to sensitive water bodies (Sharpley and Withers, 1994). In our study, concentrations of extractable P (Texas A&M extractant described in Hons et al., 1990) in the surface 15 cm of soil increased with increasing manure and effluent rates (Fig. 3). The largest increase in soil P occurred after the first year of solid manure application even though the least amount of P was applied in 1995 (Table 2). The solid manure was surface-applied and not incorporated into the soil, so most of the P probably stayed on the soil surface. This is confirmed by analysis of soil from the 15- to 30-cm depth in the manured portion of the plots. Extractable P in soil from this depth was not significantly different among treatments and averaged 6 mg kg<sup>-1</sup> (data not shown). Concentrations of extractable P in the soil from the filter strips were not different among treatments in either the 0- to 15-cm (average of 10 mg kg<sup>-1</sup>) or 15- to 30-cm (average of 4 mg kg<sup>-1</sup>) soil layers (data not shown).

Texas regulations (at the time of this study) state that when fields used for manure applications exceed 200 mg kg<sup>-1</sup> extractable P (using the Texas A&M extractant) in the surface 15 cm of soil, manure rates must be limited to rates equal to the amount of P removed in harvested forage, rather than based on N removal rates (Texas Register, 1994). Soil-test P increased from 8 to 30 mg kg<sup>-1</sup> at the high manure rate, and 8 to 16 mg kg<sup>-1</sup> at the medium rate during 3 yr (Fig. 3). Assuming these increases are linear each year, our data indicate that moderate rates of lagoon effluent could be applied for several years to a switchgrass sod on a Windthorst soil before the 200 mg kg<sup>-1</sup> limit would be reached. However, this ignores other consequences such as surface



**Fig. 3.** Changes in extractable P (using the Texas A&M extractant) in the surface 15 cm of soil as a function of manure rate and time. Data are means of four replicates. Standard error bars represent the pooled standard error from the analysis of variance and apply to all treatments within a date.

**Table 4.** Rainfall at Stephenville, TX (measured 1 km from the study site) during the experiment. Long-term (30-yr) average data are from records kept at the Texas A&M University Agricultural Research and Extension Center at Stephenville.

Month	1995	1996	1997	30-yr avg.
	mm			
January	24	12	10	43
February	13	7	211	45
March	98	28	84	41
April	56	66	113	87
May	132	74	88	118
June	98	69	163	63
July	217	71	34	62
August	77	236	44	49
Sept.	83	104	28	76
October	66	73	116	82
November	16	102	24	45
December	18	3	106	39
Total	896	918	1021	750



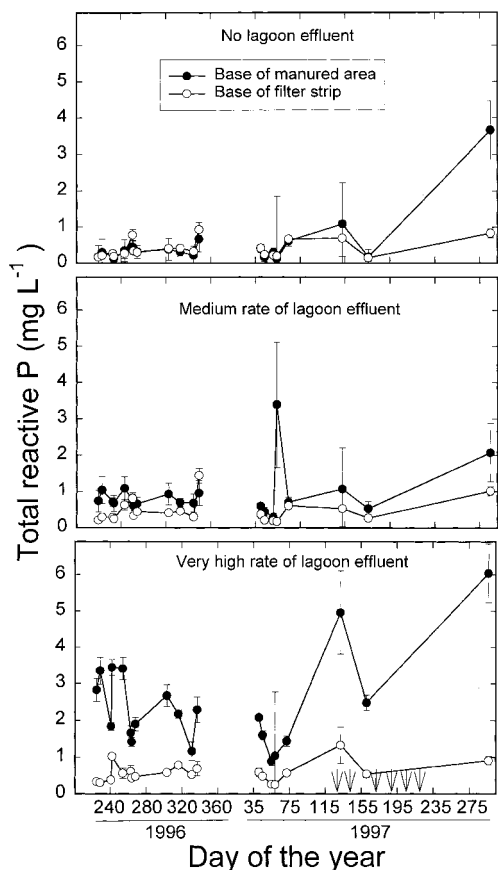


Fig. 4. Concentrations of total reactive P in surface runoff water from the manure-treated areas and vegetative filter strips. Effluent was applied on 16 Apr., 1 May, 20 May, and 25 June 1996 (Days 106, 121, 140, and 176; not shown on figure). Arrows indicate dates of effluent application in 1997. Data are means of four replicates plus one standard error.

runoff contamination and the need for additional N fertilizer to obtain good switchgrass yields.

#### Nitrates in Soil Water

Concentrations of  $\text{NO}_3\text{-N}$  were  $<3 \text{ mg L}^{-1}$  in soil water collected at the 46-, 91-, and 100-cm depths during 1995 to 1997 (30 rainfall events for a total of 417 samples during 3 yr). Soil water samples were obtained most frequently during the wet winter months. During late spring, summer, and early fall, switchgrass growth and evapotranspiration probably limited the downward movement of water and dried the soil profile. Two exceptions occurred when more than 200 mm of rain in July 1995 and August 1996 (Table 4) resulted in significant percolation of soil water, without elevating concentrations of  $\text{NO}_3\text{-N}$  in soil water. These results are similar to previous research with solid dairy manure applied to bermudagrass where  $\text{NO}_3\text{-N}$  in soil water remained below  $3 \text{ mg L}^{-1}$  (Sanderson and Jones, 1997). High  $\text{NO}_3\text{-N}$  concentrations ( $11$  to  $33 \text{ mg L}^{-1}$ ) were measured in soil water below a bermudagrass-ryegrass sod that received  $1000 \text{ kg N ha}^{-1} \text{ yr}^{-1}$  from dairy waste slurry in eastern Texas (Johnson et al., 1995). Nitrate N concentrations were much lower ( $2$  to  $8 \text{ mg L}^{-1}$ ) at manure rates less than  $1000 \text{ kg N ha}^{-1}$  in that study.

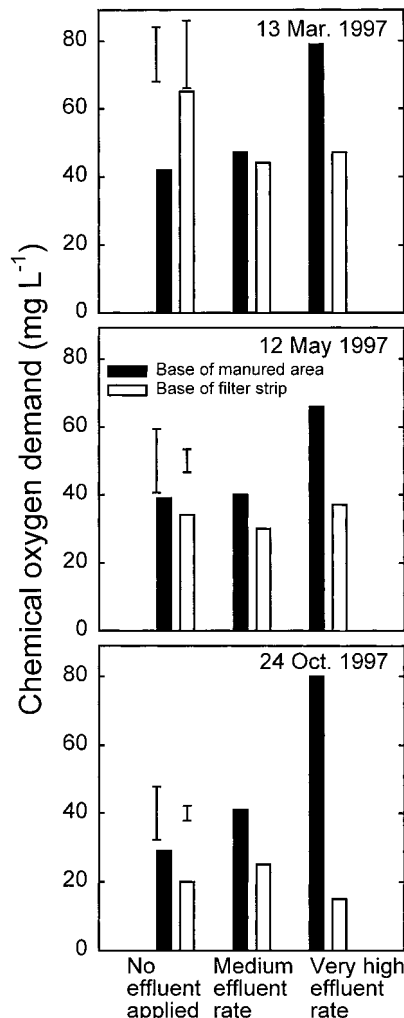


Fig. 5. Concentrations of chemical oxygen demand (COD) in surface runoff water from the manure-treated areas and a vegetative filter strip. Data are means of four replicates. Error bars (representing the pooled SE from the analysis of variance) above the solid column apply to data from the manured area. Error bars above the open column apply to data from the filter strip area.

#### Surface Runoff

Runoff occurred on 19 dates in 1996 and 12 dates in 1997. However, on seven dates in 1996 and four dates in 1997 surface runoff occurred on only a few plots and was not collected in both samplers. Therefore, these dates were omitted from the analysis. Rainfall was below normal in January through May 1996 (Table 4) and little runoff occurred. Most surface runoff occurred in August, September, and November when rainfall was much above normal.

In 1996, effluent applications were completed by the end of June (Table 1) but runoff was not collected until mid-August when heavy rains occurred (Table 4). In 1997, high total reactive P concentrations in surface runoff water occurred a few days (9 May, Day 129) after effluent had been applied on 6 May (Day 125; Fig. 4). Fifty-two millimeters of rain fell within 2 d of application. Generally, the sooner rain falls after manure application the greater the surface runoff loss of nutrients.

Nutrient export decreases with each subsequent rain and runoff event (Kirchman, 1994). Edwards and Daniel (1993) recommended that if concentrations of N or COD are of concern in surface runoff from grass sod treated with swine manure, then an interval of 3 to 4 d between application and subsequent rainfall is needed for manure to dry and reduce surface runoff losses. If P concentrations are of concern, then only 1 d may be necessary. Ideal manure spreading conditions have been described as those with low probability of rain with 2 d of spreading and a rain-free period for 3 d after spreading (Parkes et al., 1997).

Concentrations of total reactive P in surface runoff water increased ( $P < 0.05$ ) with increasing amounts of lagoon effluent applied in 1996 and 1997 (Fig. 5). This is consistent with research conducted with lagoon effluent on bermudagrass runoff plots (Sweeten et al., 1995). In that study, total P concentration was  $0.5 \text{ mg L}^{-1}$  in runoff water from control plots,  $1 \text{ mg L}^{-1}$  in runoff water from plots treated with dairy lagoon effluent at  $100 \text{ kg N ha}^{-1}$ , and  $3 \text{ mg L}^{-1}$  in runoff from plots with effluent applied at  $200 \text{ kg N ha}^{-1}$ . Total reactive P concentrations from surface runoff of control plots were frequently less than  $0.5 \text{ mg L}^{-1}$  in our study. The 16.4-m vegetative filter strip effectively reduced total reactive P concentrations in surface runoff from the manured portion of the plot. Reductions in total reactive P as a result of the vegetative filter strip ranged from 0 to 95% (average of 47%) at the medium effluent rate and 19 to 91% (average of 76%) for the high rate of effluent during 1996 to 1997.

The filter strip was also effective in reducing COD concentrations in surface runoff water (Fig. 4). Percentage reductions in COD were 40% for the very high effluent rate in March 1997; 25 and 44% for the medium and very high rates, respectively, in May 1997; and 39 and 81% for the same rates in October 1997. Levels of COD were highest ( $P < 0.05$ ) at the very high rate of effluent but not significantly different between the zero and medium rates. Although we did not measure the COD of the raw lagoon effluent, Sweeten and Wolfe (1994) reported COD values of 400 to  $650 \text{ mg L}^{-1}$  for raw effluent from secondary treatment lagoons sampled near Stephenville.

The reductions in P and COD of surface runoff water that we obtained with switchgrass filter strips are comparable with results from other studies. Vegetative filter strips 15 m long reduced ortho-P concentrations from 12 to  $1 \text{ mg L}^{-1}$  in surface runoff from tall fescue (*Festuca arundinacea* Schreb.) plots treated with poultry litter (Srivastava et al., 1996). Up to 85% of ortho-P was removed by vegetative filter strip treatment (12.2 m long) of surface runoff from tall fescue plots treated with beef cattle manure (Lim et al., 1998). Bingham et al. (1980) reported a 34% reduction in COD and a 78% reduction in ortho-P from tall fescue plots treated with poultry waste with a vegetative filter strip (waste area to filter strip ratio of 1.0). Switchgrass filter strips 3 or 6 m wide reduced ortho-P concentrations by 38 and 46%, respectively, in runoff created with a rainfall simulator (Lee et al., 1999).

## SUMMARY AND CONCLUSIONS

Switchgrass filter strips effectively reduced total reactive P and COD concentrations in surface runoff water from manure treatments. Biomass yield of switchgrass increased with increasing manure N rate; however, N and P recovery in biomass was low ( $<20\%$ ). Manure could effectively substitute for inorganic fertilizer in switchgrass biomass production with dual use of the switchgrass as a vegetative filter strip. Our system used a manure-treated area to filter strip width ratio of 1. In practice, the manure-treated area would probably be greater than the filter strip width. Others have found that the effectiveness of filter strips varies with ratio (Dillaha et al., 1989). Thus, more work should be done to define appropriate ratios for this type of system to optimize nutrient reduction and minimize land area needs. Some biomass could be harvested from the filter strips but yields would be low (about 3 to  $5 \text{ Mg ha}^{-1}$  for our region based on yields from the control plots). Warm-season grasses are typically used as forage. Coupling biomass production with a vegetative filter strip conservation practice could provide a "green" farming practice to reuse manure nutrients from dairy manure, produce an alternative agricultural commodity, and protect the water resource in the Upper North Bosque River watershed.

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